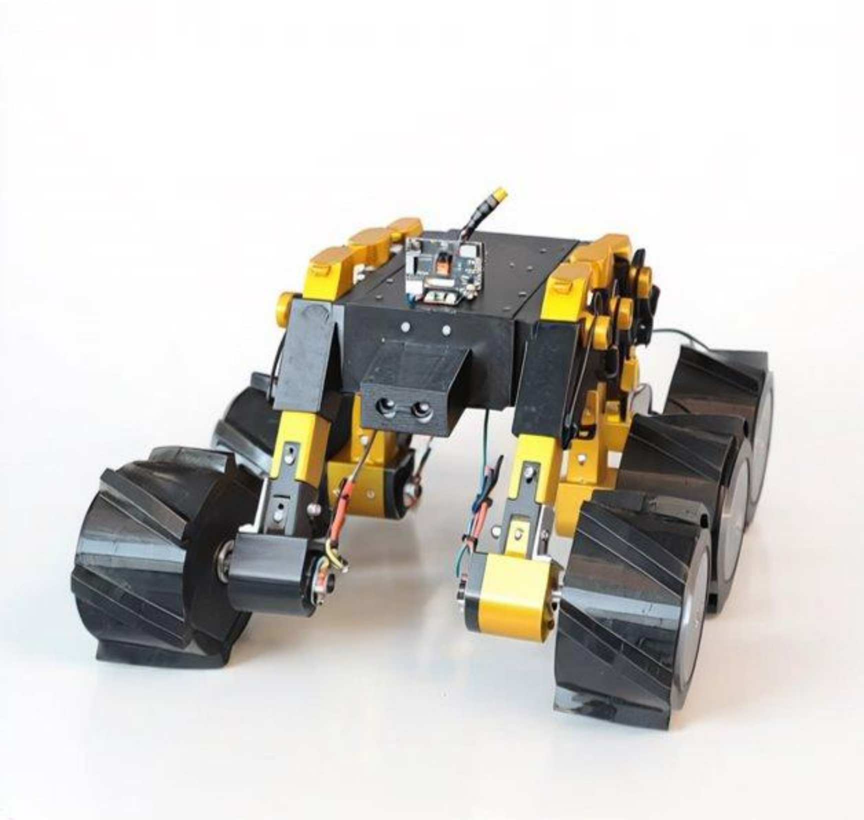
# Rover on The Red Horizon



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# Introduction

Mars rovers are designed to navigate and explore the surface of Mars in harsh and unpredictable conditions. The planetary surface presents a significant challenge to engineers, especially in the development of autonomous rovers, capable of operating without human interaction. Autonomous rovers must be able to avoid obstacles, navigate rough terrain and make real time decisions using onboard sensors. Due to the significant distance between Earth and Mars, communication delays can range from 3 to 21 minutes for a one-way signal. This makes real-time control difficult, increasing the risk of damage or mission failure.

As part of the Colorado Space Grant Consortium (COSGC) Robotics Challenge, teams design and build a rover to autonomously operate and navigate through Mars-like terrain. The challenge takes place in the Great Sand Dunes National Park, simulating the Mars-like terrain, where the rovers must complete a variety of tasks. These tasks include, but are not limited to, traversing soft and/or compacted sand, avoiding obstacles, and climbing uneven terrain, all while operating without GPS. The rover must also meet challenge constraints of weight (1-5kg), a max budget of $500 and size limitation of a cat.

# Design Process

During the design process, the rover underwent many design changes with several design configurations being evaluated before selecting a final system. An initial four-wheel design offered simplicity and low weight but lacked sufficient stability and obstacle traversal capability. An eight-wheel design with a bogie suspension system provided excellent traction and stability; however, it exceeded the weight limit, weighing approximately 6.8 kg. To address this issue, the design was refined into a six-wheel configuration, which maintained many of the advantages of the eight-wheel system while reducing weight to 4.7 kg.

The final design uses a differential drive system with three motors per side, allowing effective steering and improved traction while remaining within constraints. The rover chassis was constructed using a combination of 3D-printed materials and machined aluminum components to balance strength and weight. A modular design approach was used to simplify assembly and allow for easy repairs and modifications. A bogie-style suspension system was implemented to improve performance on uneven terrain.

This system distributes weight across multiple wheels and maintains ground contact, increasing stability and traction when traversing obstacles such as rocks, sand mounds, and depressions. The drivetrain consists of independently powered wheels, each driven by a DC motor. This configuration improves traction and provides redundancy, ensuring continued operation even if a single motor fails. Differential steering is achieved by varying the speed of the left and right sides of the rover.

The rover is controlled using an Arduino Mega 2560, selected for its large number of input/output pins and compatibility with multiple sensors. Motor control is implemented using multiple SparkFun Motor Driver - Dual TB6612FNG modules, enabling efficient control of all six motors. The electrical system was designed to be simple and reliable. Motor drivers were connected in parallel, and a shared standby control line allows all motors to be enabled or disabled simultaneously. This reduces wiring complexity and improves overall system robustness. To enable autonomous navigation, the rover integrates both distance and vision-based sensing systems. Ultrasonic sensors mounted at the front and rear provide real-time distance measurements for obstacle detection and collision avoidance.

A vision system using the HuskyLens AI Camera provides object detection and tracking capabilities, allowing the rover to respond dynamically to its environment. Sensors are strategically placed to maximize coverage, with primary detection in the forward direction and additional safety coverage at the rear. The rover was designed to operate in harsh outdoor conditions. Electronics are enclosed to prevent sand intrusion, and structural components are reinforced to withstand impacts and vibrations. Materials were selected to tolerate exposure to sunlight and temperature variations.

Manufacturability was also a key consideration. Components were designed in modular sections for 3D printing and assembled using standard hardware. Commercial off-the-shelf components were used where possible to reduce cost and simplify implementation.

## Construction and Assembly

The primary structural material selected was Polyethylene Terephthalate Glycol (PETG), which was used for the frame, legs, motor mounts, wheel hubs, and protective covers. PETG was chosen for its lightweight properties, ductility, and high resistance to heat making it suitable for operation in outdoor environments. The material was printed in black and gold to reflect our school colors.

The rover’s tires were fabricated using Thermoplastic Polyurethane (TPU), allowing for the creation of custom wheels and tread patterns. This provided improved shock absorption when traversing uneven terrain or encountering obstacles. For sensing and navigation, the system utilized a Husky Lens AI Camera for object detection and recognition. Front and rear ultrasonic sensors served as redundant detection systems in case the camera failed to identify obstacles.

The initial design featured eight independently driven motors and wheels, enabling full control of forward motion, reverse motion, turning, and stopping. The rover was powered by an Arduino Mega, programmed using Arduino software to process sensor inputs and control locomotion.

During the first build, the rover exceeded the weight constraint by approximately 2 kg. To address this, the design was re-evaluated to reuse as many components as possible while reducing overall mass. The system was reconfigured into a six-wheeled platform, and the frame size was reduced by approximately 75%. Despite the size reduction, all electronic components were successfully integrated within the hull, and a second version of the rover was assembled.

Key structural areas such as the front and rear legs were reinforced with custom fabricated aluminum supports, as these regions were expected to experience the highest impact loads during operation. The wheels were designed with custom mounting interfaces, allowing them to be securely bolted to the motors while still enabling easy disassembly for maintenance or upgrades. Thin aluminum disks were incorporated into each hub to reduce wear between the motors and PETG components and to help retain the TPU tires.

The electrical components were housed inside the main hull which was reinforced using 90° brackets and assembled with a combination of stainless-steel screws and Allen bolts. Aluminum disks and corresponding hub surfaces were sanded, cleaned with rubbing alcohol, and bonded using two-part epoxy to ensure a secure fit. Wiring was organized and secured with zip ties, and the hull was sealed with caulk to improve water resistance.

To allow for quick battery replacement, a removable battery system was implemented. Sheet metal was cut, bent, and mounted to form a battery holder sized to the power supply. Batteries were secured using rubber bands, enabling rapid swaps in the event of low power. Following assembly of the second iteration, the rover was ready for performance testing and evaluation.

# Testing

The first stage of testing consisted of simulations and isolated testing. Finite Element Analysis (FEA) was used to analyze the motor mounts for potential failure points. Since FEA is difficult to use for anisotropic material properties, which are exhibited by 3D-printed materials like PETG, FEA was used for qualitative analysis. The location of failure modes were identified, which was later shown through actual part failure, and can be seen below in Figure 1. The motors and sensors were also tested independently to ensure each part functioned correctly.

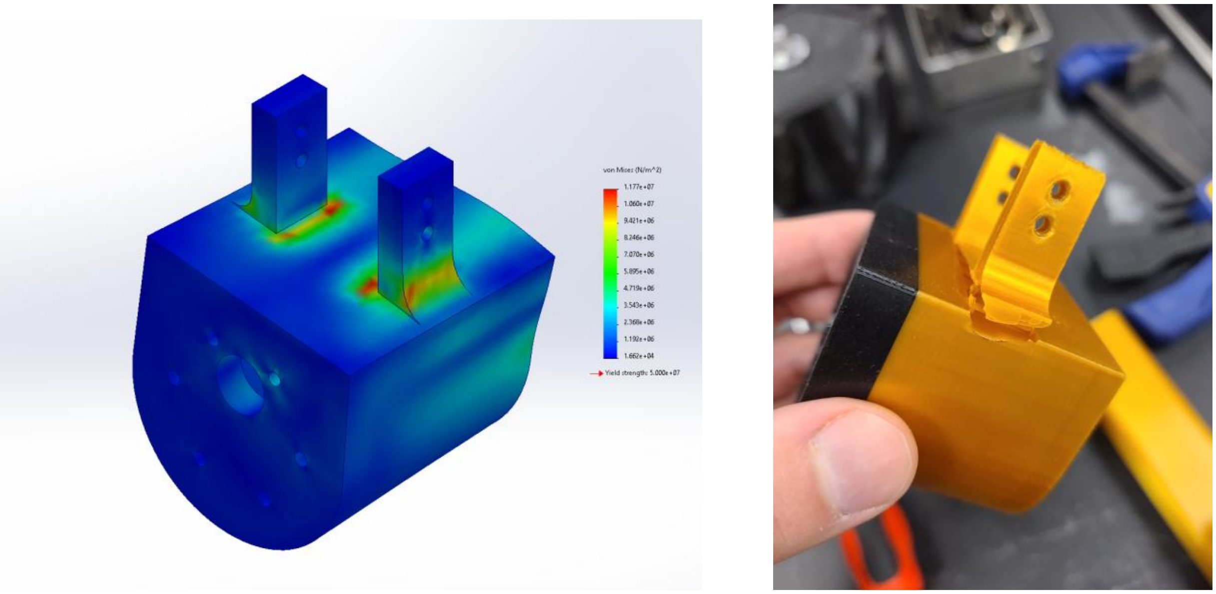


*Figure. 1: a) Location of Motor Mount Failure Mode from FEA, b) Part Failure During Testing*

The second stage of testing occurred after assembly. The sensor-Arduino connections were tested to ensure that sensors communicated effectively with the Arduino. Once that was completed, the next step was ensuring that decisions were made efficiently using data from all three sensors and was additionally tested to ensure that the Arduino could utilize readings from all three sensors. The weight was also measured at this point, ensuring that the rover was within the required weight range. As parts were added and removed, the rover would be reweighed to ensure weight compliance. Finally, basic movement was tested. The rover was given basic code to ensure motor directions were implemented properly, and movement was correctly implemented.

The final stage of testing was iterative and focused on the 3D-printed parts and obstacle avoidance logic. The code was constantly fine-tuned to ensure that the two Ultra Sonic sensors and the HuskyLens camera worked together effectively to avoid obstacles. Since the rover was driving during this phase, the frame was also tested via obstacle detection errors. Whenever the rover collided with an obstacle, it highlighted the parts that could and could not survive collisions with obstacles. During this phase, two critical errors were found and corrected: the motor mount failing from a collision, shown in Fig. 1, and the wheel not properly attaching to the motor rod. Finally, the rover was tested on a sand-like surface to ensure that movement and obstacle avoidance transferred well. The results showed that sand will slow down movement speed, requiring the overall base speed to be raised. Additionally, sand showed that low torques would cause the rover to get stuck. This presented as the motors stalling or the wheels spinning in place as the rover dug itself into a hole.

# Discussion and Conclusions

In some ways, Lil' Clyde performed well. However, the rover also had a number of flaws and there were several design decisions that would be made differently with the experience and results of the testing of the rover.

## Strengths of the rover

The rover had several strengths and elements that performed well.

First and foremost, the modularity of the design proved crucial to addressing failures during assembly and during the challenge. When the initial rover design, "Big Clyde", was found to be significantly over the allowed mass, dramatic design changes needed to be made in a very short timeframe. Thanks to the modular design, a new configuration of existing parts could be created in a relatively short period with minimal need for the manufacture of new components. This redesign was certainly a setback, and it played a significant role in the limited testing time, the setback would have been much more catastrophic with a nonmodular design. Additionally, the modularity of the design allowed for the rapid repair of the rover in the field on competition day with only basic tools when the rover became damaged during operation.

An additional strength of the rover was the use of a visual camera for navigation. While its utility was limited by the navigation code, the camera offered a great deal of information for the rover to use. Had the navigation program had more time for testing and iteration, the use of a camera with object tracking capabilities could have resulted in excellent obstacle avoidance capabilities.

Another strength of the rover came in its long wheelbase and high ground clearance, which allowed it to surmount relatively large rocks and trenches compared to many other wheeled entrants, though it didn't perform to the same extent as many rovers with legs or tracks in this respect.

## Weaknesses of the rover

Many flaws were identified with the rover. Some were addressed and resolved while others were not due to a lack of time or resources to make the necessary changes.

The most significant issue was the excessive weight of the rover. Because this is elaborated on extensively elsewhere, it will not be here.

Even with the weight reductions of Lil' Clyde over Big Clyde, weight remained an issue. Or rather, the rover possessed insufficient torque for its weight, in part due to the reduction of the number of wheels and motors. A simple solution to this problem would be to replace the motors used with ones with a larger final drive ratio, thereby providing a higher torque and lower RPM. However, by the time the torque issue was identified, there was neither enough funds to purchase new motors nor enough time to account for shipping. Another possible solution considered was the creation of a gear mechanism for the same purpose of increasing torque. This was not pursued due to the difficulty of the undertaking, the weight such a system would add, the high likelihood of failure, and the lack of time for proper testing and iteration for the subsystem.

An issue that was resolved during assembly was the weakness of the wheel-motor shaft interface. Initially, the PETG wheel hubs simply had an axle hole in the same D-shape as the motor shaft. However, after early testing this axle hole wore out and the wheels began to slip. Aluminum mounts were created to resolve this issue, but then the interface between the mounts and the wheel hubs began to fail due to the lack of material on the wheel hubs for the interface screws to "bite" into. This was finally resolved by the addition of an aluminum backing plate to secure the interface between the wheel mount and wheel hub. Had the issue of the security of the wheel been anticipated from the start, aluminum mounts could have been designed from the start and fitted to wheel hubs designed to accommodate them, saving time, money, and weight.

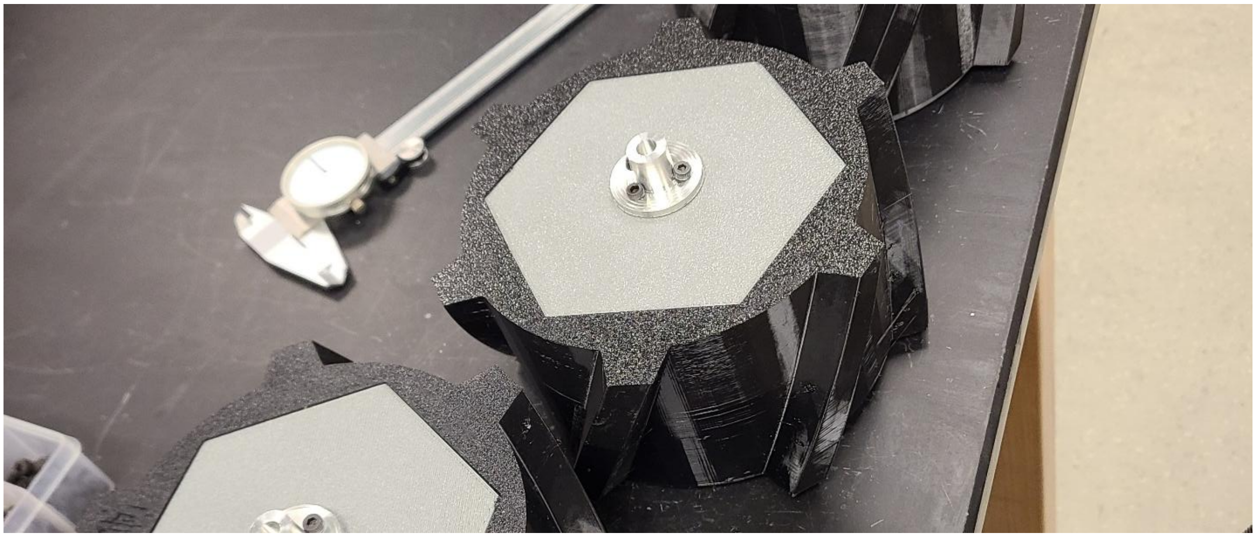


*Figure. 2: machined aluminum mounts affixed to the wheel hubs. Note the aluminum backing plates have not yet been added.*

The rover was damaged several times. Most frequently the breaks occurred at the joint are between the motor mounts and legs. Increasing the amount of material in these areas either by changing the geometry or using a higher infill would have increased the strength of the parts involved. However, the failures always manifested as cracks along layer lines, and these cracks were also present in other areas of the rover. So, this issue could also potentially be resolved by changing the print orientation of the parts so that the expected tensile and shear loads act parallel to the layer orientation rather than creating forces that pull layers apart, which results in far lower strength of the material. Aluminum reinforcements were added to joint areas that were weak, but unfortunately the weakness of the central leg joints was not seen as a potential issue prior to challenge day.

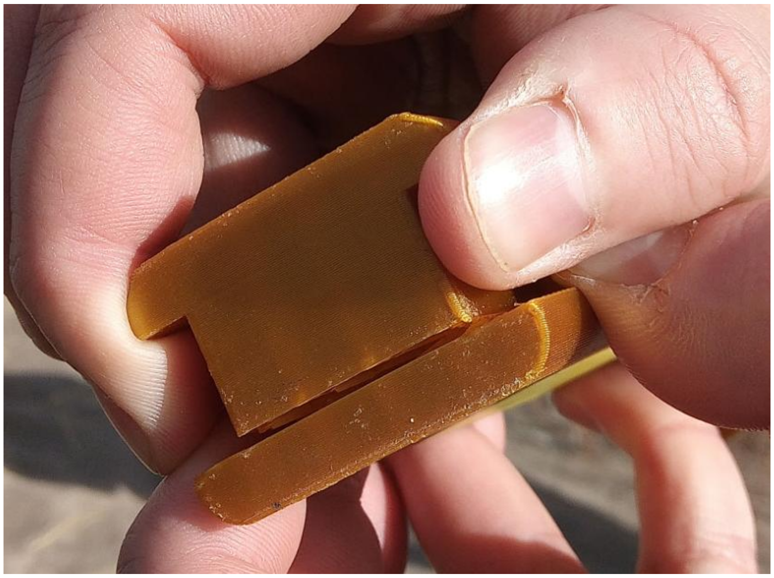


*Figure. 3: Example of layer separation failure*

Another issue with the PETG material was the inefficacy of screws when used in a blind tensile fitting. In certain areas of the assembly, screws were used to secure one part to another. But when placed in tension the screws quickly stripped their holes. Bolts, which were used in other areas where both sides of the joint could be accessed, were much more effective. An iteration of the rover design would do well to make use of bolts or lap joints rather than screws.

The ultrasonic sensors were somewhat ineffective largely due to their limited field of view. This resulted in the rover only being able to detect obstacles roughly along its centerline, and not, for example, a rock that one set of wheels is about to collide with. An improvement over ultrasonic sensors could be LIDAR which a small number of other teams used on their rovers.

Another issue with the navigation system was the lack of information on the position and orientation of the rover. An IMU was planned to be part of the sensor suite, but was never fitted due to time constraints, and instead it was planned to use the motor activation times to track the rover’s position and orientation. This system was never fully implemented either due to a lack of time for testing the code. Even so it likely would not have worked anyways due to the inconsistent traction on the course. A future iteration of the rover would benefit greatly from the proper implementation of an IMU to prevent the rover from colliding with the walls of the course.

The suspension system, while simple and strong, was less effective than expected due to friction being sufficient to support the weight of the rover. This issue was particularly pronounced later into the challenge because of the sand and wind on the course. Additionally, the rearmost set of wheels, relative to the motion of the rover, were essentially unsprang because of their angle. This wasn’t considered a problem when the rover had eight wheels but by the time it was reduced to only four, half of the suspension would be inoperable. A torsional system, while more complex, would have been more effective especially if the rover was designed for four wheels.

## Changes to the design process

In addition to specific flaws in the design of the rover, issues were identified with the design process.

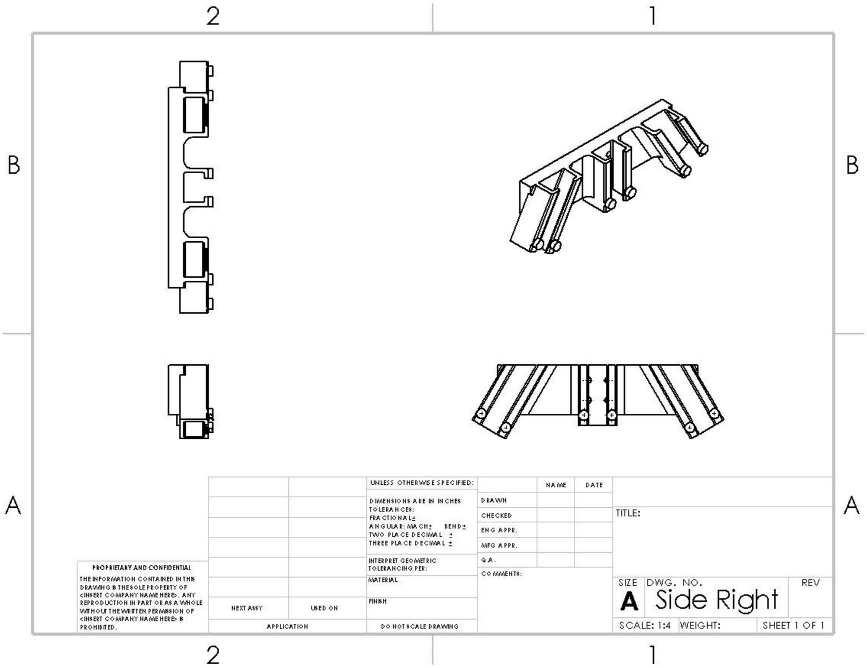
During the first semester the project progressed at a relatively slow pace; causes including delay before the start of the project, a focus on completing various documents, and the initial test rover taking significantly longer to complete than expected. Had more time been allocated to the design of the final rover during this semester, there would have been more time available for testing during the second semester.

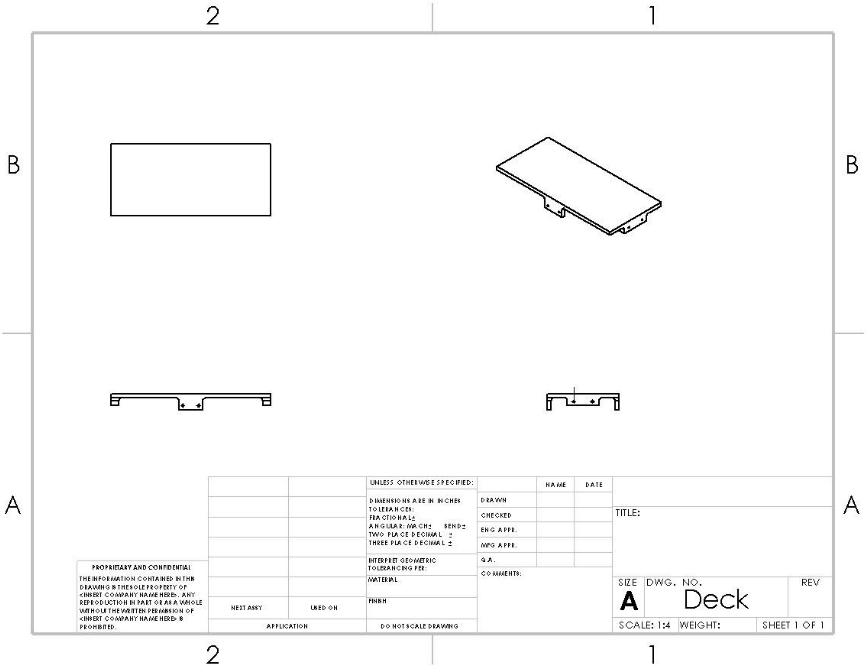
Additionally, insufficient modelling was done early in the design process. For example, the weight of the rover was estimated very early in the design process and then that mass estimate was not updated later in the design. Had a mass breakdown been done before beginning production and assembly the rover would have been identified as significantly overweight, and much time and resources could have been saved by altering the design before Big Clyde was created. The size requirements of the electronics could also have been determined beforehand, reducing the expected size requirements of the rover. Simple calculations could have been made to determine the necessary torque before motor selection, though at the time budget was considered the most pressing issue. Finally, the navigation logic could have been developed before construction and potentially implemented on a test vehicle, reducing the amount of work that would need done towards the end of the design process. In short, the time pressure was underestimated and more could have been done earlier to prevent issues that later caused delays.

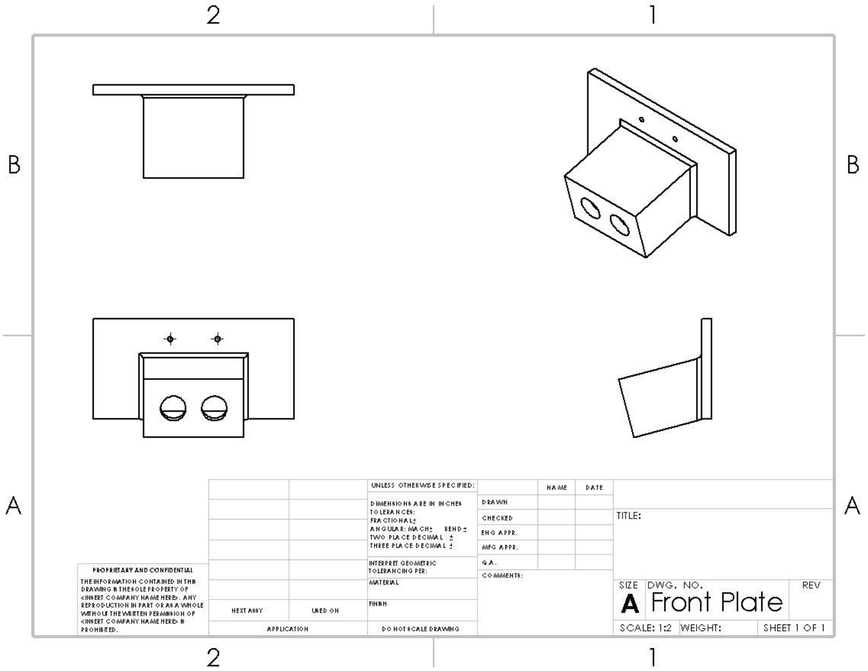
However, many of these issues resulted from the lack of information on the challenge and the process of designing and building an autonomous rover. This was the first time UCCS had participated in the challenge, and it is the hope that the documentation of our efforts and process will help inform future teams at UCCS.

# Appendix A

SolidWorks Drawings of Lil’ Clyde Structural Elements



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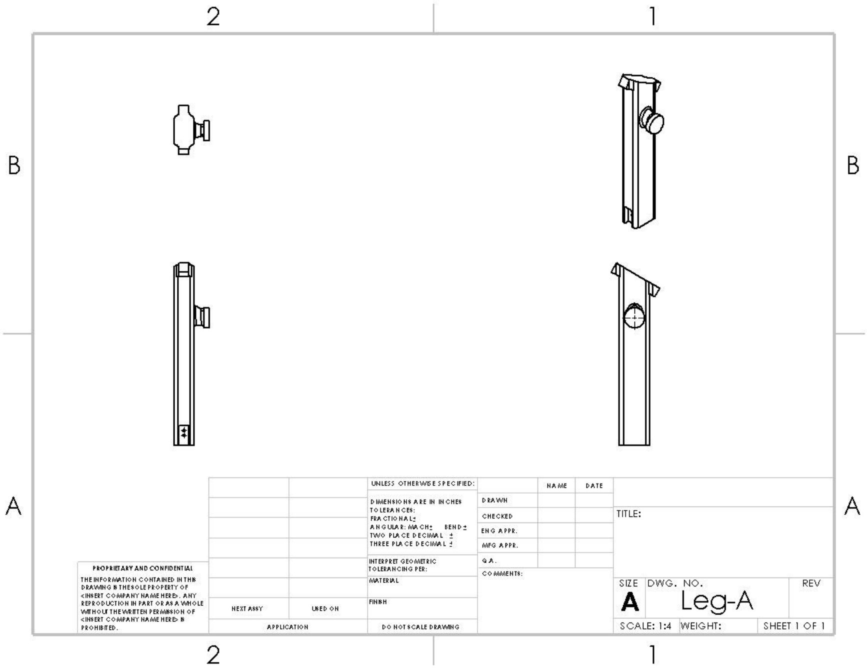
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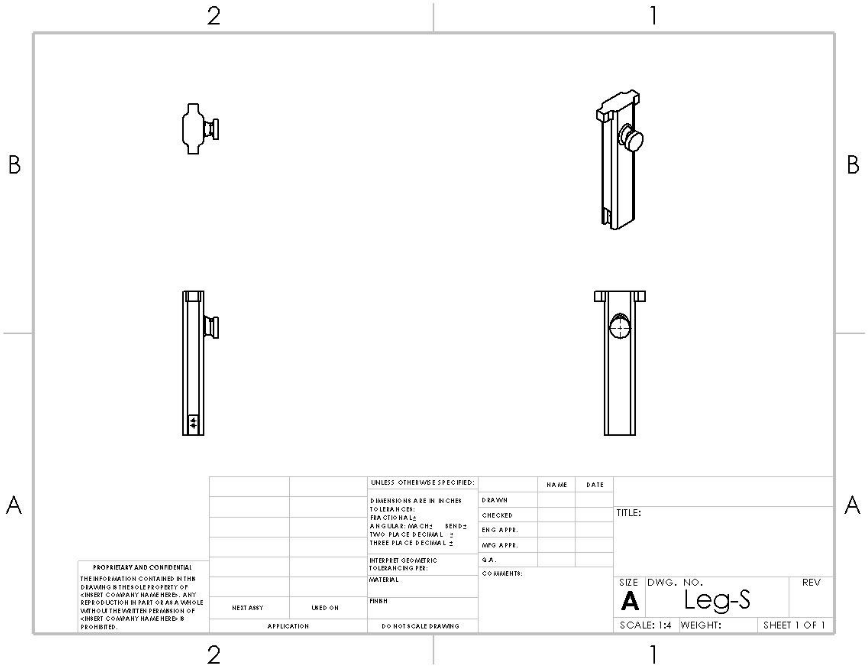

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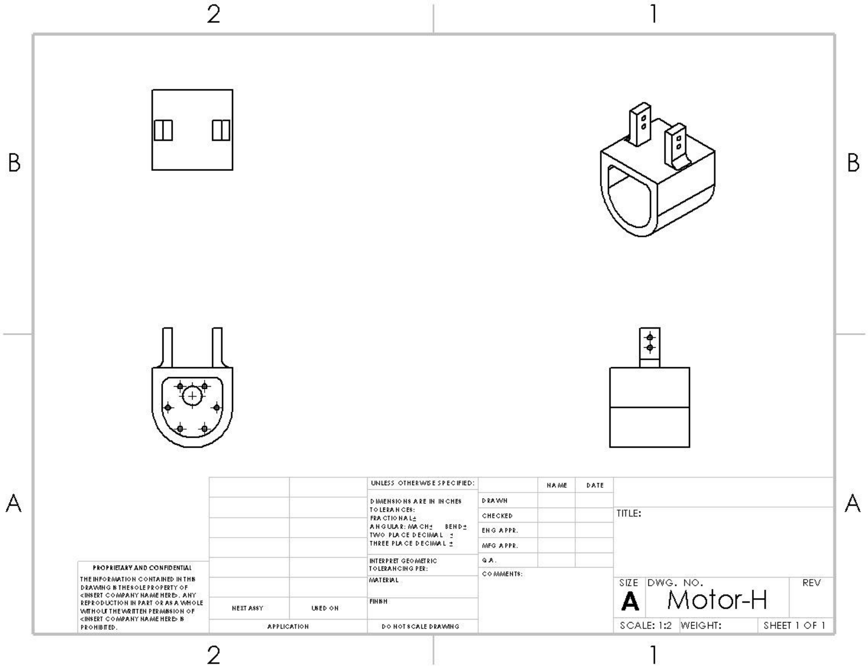

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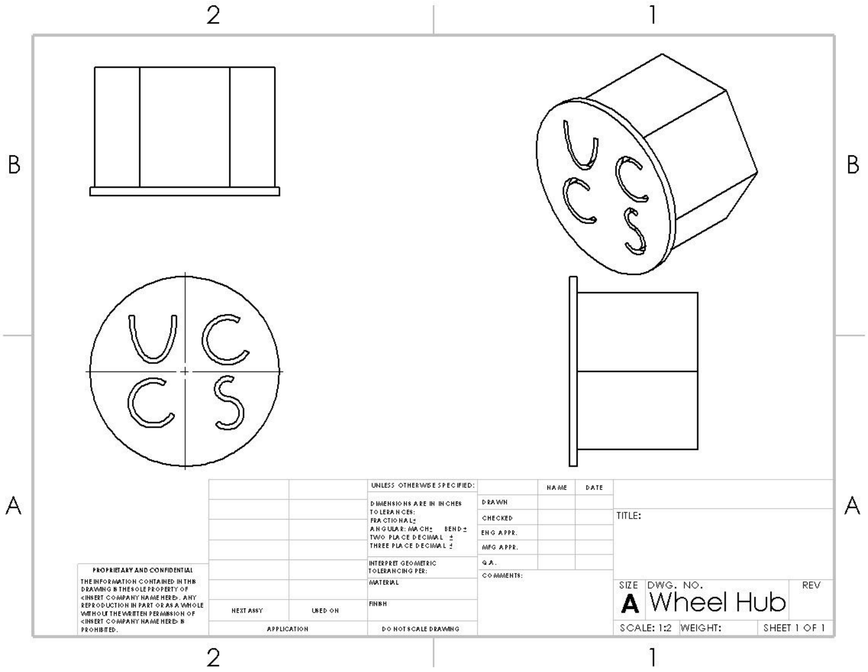
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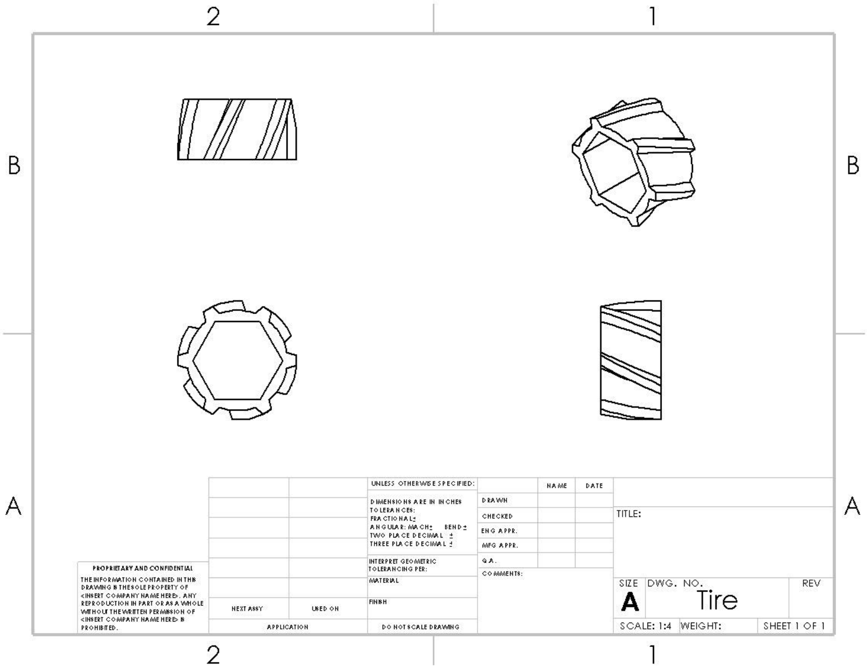
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